NBS TECHNICAL NOTE 1161

U.S. DEPARTMENT OF COMMERCE/National Bureau of Standards

Testing to Quantify the Effects of Handling of Gas Dielectric Standard Capacitors

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Testing to Quantify the Effects of Handling of Gas Dielectric Standard Capacitors

Charles R. Levy

Electrical Measurement and Standards Division
Center for Absolute Physical Quantities
National Measurement Laboratory
National Bureau of Standards
Washington, DC 20234

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, Secretary
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

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TESTING TO QUANTIFY THE EFFECTS OF HANDLING OF GAS DIELECTRIC STANDARD CAPACITORS

by Charles R. Levy

1. Abstract

A test method known as the "Handling and Stability Test" is currently being used at NBS as part of the requirement for the five-part-per-million calibration of gas dielectric standard capacitors. This test is used to achieve qualitative information on the effects of mechanical shock from shipping and handling on standard capacitors and to rank them quantitatively with respect to these effects.

2. Introduction

Nitrogen dielectric capacitors are used as the reference standards for measurements of capacitance in many metrology laboratories in the United States, as well as in many other parts of the world. Since the most common standard used has a capacity of 1000 picofarads, this report is based on tests of capacitors of this value, but an equivalent test is performed on 10 and 100 pF capacitors as well.

Recognizing the range of mechanical shocks which these capacitors may receive in service or in transport, NBS devised tests to confirm the mechanical integrity of the units before calibration and to determine the magnitude of any related effects [1]. Such effects may then be taken into account quantitatively in the systematic error portion of the uncertainty statement. The results of the handling test were also expected to be useful to guide the user concerning changes in capacitance to be expected as a result of transport and normal handling. The use of standard gas filled capacitors in transport service is rapidly becoming a more important basis for the intercomparison of reference standards among calibration laboratories. A similar approach, based upon the use of a compressed gas capacitor (specifically designed for high voltage) in transport service, has also been investigated in connection with the intercomparison of high voltage capacitance measurements [2].

The test procedure has also been used for the development of a very stable, transportable capacitance standard. In particular, the results of these tests were used in the selection of capacitors and in the design of a suitable transport box for shipping the capacitors.

If the procedures described within this paper are used, gas dielectric capacitors not normally shipped to a primary reference facility may be tested to identify possible handling problems that may not otherwise be detected. In some metrology laboratories, step-up or step-down methods are used (3, 4, 6, 7, 8) to compare capacitors having a range of value with a high quality (e.g., fused silica) reference capacitor. In such cases, the uncertainties assigned to the measurements should include appropriate allowances for capacitance changes associated with normal laboratory handling. The handling test procedures are an effective tool for this purpose and, in those laboratories having the necessary facilities and data analysis skills, there is a significant possibility for reducing the cost of traceability to primary standards. Such cost savings may result from a reduction in the number of reference standards in inventory to replace those taken out of service for calibration at a remote facility, a reduction of the cost of a larger number of such calibrations, and a reduction in the risks of shipping fragile devices.

3. Methodology

Tests simulating the acceleration forces during various types of handling had to be defined. Some guidance in this regard was obtained from the manufacturers' specifications. On the basis of these tests, specialized equipment, relatively simple in design, was developed by Jerome Morrow and George Free of NBS [1]. This equipment and the procedures used to affect these tests are described in later portions of this document. In addition, dimensions of the equipment are given in Appendix 2 as an aid to those who wish to duplicate it.

The tests which have been developed address many of the common handling problems users may encounter. The test names and their purposes are:

- CONNECTOR TEST - Determines looseness of either or both connectors and associated parts. Also used to determine conductance problems that may be due to poor bonding of the connector to the case of the capacitor standard, poor solder joints, or loose inner pins of the connectors.

- ORIENTATION TEST - Used to determine the change in capacitance due to a ninety-degree rotation of the capacitor from its upright position; i.e., to a position of lying on its side. The capacitor is tested six times, once to each side. Excessive changes may indicate looseness of fasteners within the capacitor housing.

- ANGLE 3 DEGREES - Most lab table surfaces vary from the horizontal and this test was planned [1] on the basis of the estimated worst case in normal calibration laboratory operations considering a survey within NBS. The value of three degrees does not reflect a sampling of other laboratories. The change in measured capacitance allows the user to relate errors to surface differences of lab tables.

- TILT TEST - This test was devised to check for movement of component parts within the capacitor housing that may not be detected by measurement of the standard capacitor in its normal resting position.

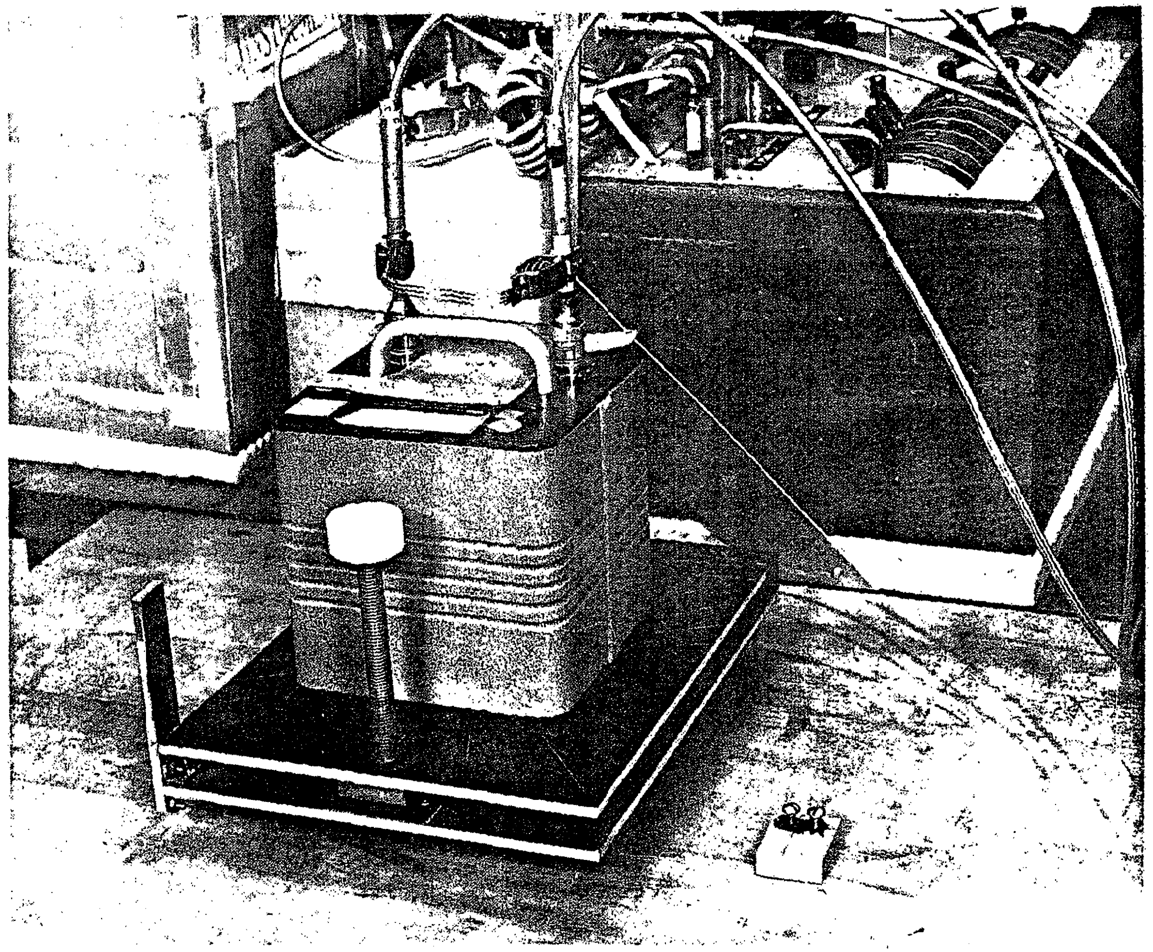

Figure 1. Tilting table for angle test.

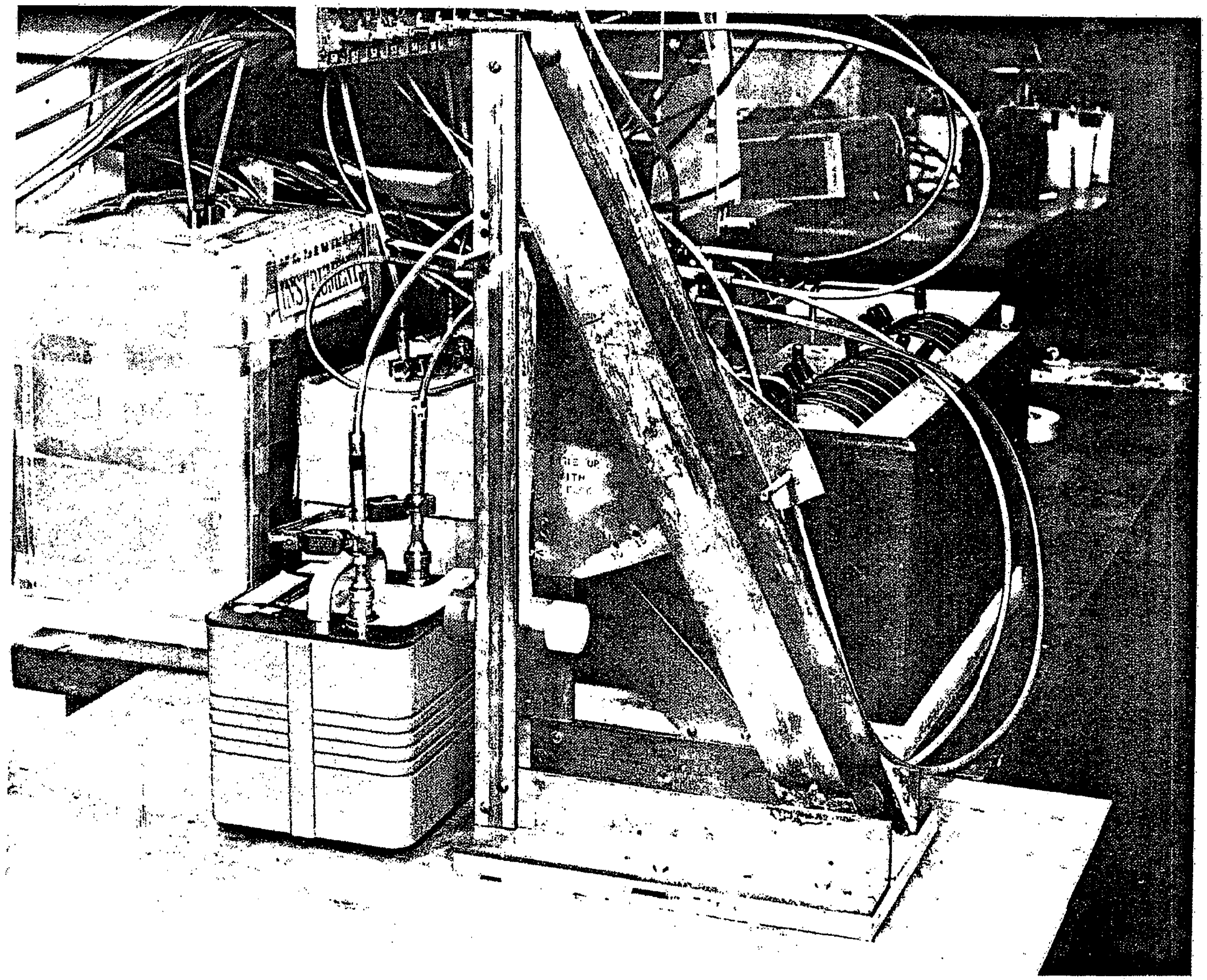

Figure 2. Special fixture for knock test.

- o KNOCK SOFT OR HARD TEST - To simulate impacts the standard capacitor receives while in transit or through rough handling in the lab.

- o DROP TEST - Designed to simulate the capacitor standard being dropped during transport or excessively rough handling within the users' lab or shipping facility.

4. Equipment Fabricated for Tests

Special equipment was constructed at NBS to accomplish the tests described in this paper. For the convenience of those interested in reproducing this equipment, drawings are included following the text.

For the angle test, a tilting table was built consisting of a platform supporting a hinged plate that can be tilted in half degree increments. Three adjustable feet are used to level the platform. To adjust the angle of the tilting plate, an adjustable screw rod with a large knob is provided as shown in figure 1. This knob can vary the angle of the adjustable plate from zero to three degrees or more as required. However, as an angle of three degrees was selected as the most useful test angle and to save time in adjustment of the elevated table, a removable block with an adjustable screw was fashioned and fixed in the three degree position.

For the knock tests, a stand was made to support a hammer with interchangeable heads. Referring to figure 2, an angle plate on the side of the stand was marked off in increments of 10, 15, 20, 25, and 45 degrees. A stop is used to prevent the hammer from going back further than the desired angle. The plate is movable in the vertical plane to accommodate taller capacitors without affecting the desired striking angle.

The hammer selected was manufactured by the Nicholson File Co., Providence, R. I., and is designated as No. 155. The two detachable heads used are manufactured by J. H. Williams and Company, United Greenfield Division of TRW, Inc., Buffalo, N. Y.; they are designated as HSF-15-SS (soft head) and HSF-15-N (hard plastic head)[1].

In the case of the drop test, a block of wood having dimensions 3.8 cm (1.5 inches) by 8.9 cm (3.5 inches) was used. By inserting this block with the smaller dimension under one of the capacitor sides and then quickly removing it, one drops the capacitor to that side. This test simulates dropping a capacitor contained within an appropriate shipping container on one of its sides or corners.

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[1]Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

5. Testing Procedure and Results

To produce uniform results, a systematic method of testing was developed. The results collected over the years have, therefore, consistent significance and may be examined for indications of impending problems, or to predict the direction in which the value of the capacitor may change. They also provide a history of the handling and stability of the standard. Furthermore, the test results can be used to screen capacitors not suitable for precision measurements and to select capacitors for a bank.

A long set of coaxial leads was connected to the test capacitor and to the appropriate transformer tap on the NBS-TYPE 2 Bridge (8, 9). A known capacitance standard was connected to the appropriate tap on the standard side of the bridge as outlined in Table 1.

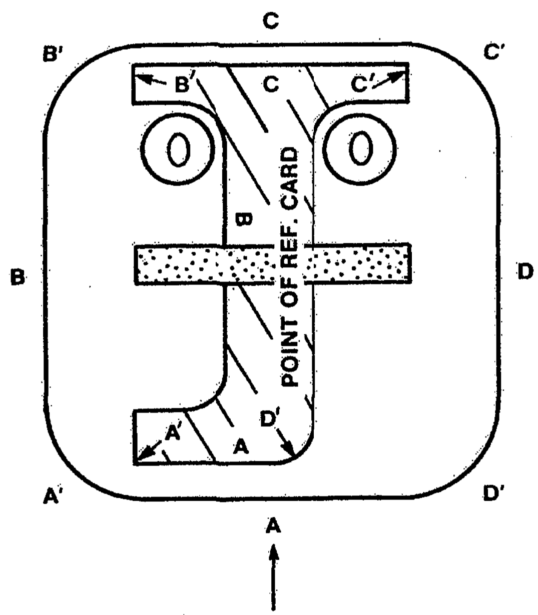
Table 1. Connection of test unit (unknown) and standard reference capacitor to NBS-type 2 bridge

Test Capacitor		Standard Capacitor	
Nominal Value	Bridge Transformer Tap	Nominal Value	Bridge Transformer Tap
1000 pF	+ 1 Fx	100 pF	- 1 Fs
100 pF	+ 1 Fx	100 pF	- 1 Fs
10 pF	+ 1 Fx	10 pF	- 1 Fs

The procedure adopted at NBS provided for testing the capacitors in a specific order: connector, orientation, angle three degrees, tilt, knock soft, knock hard, and finally the drop test (1). The detailed description of each is given later in this paper.

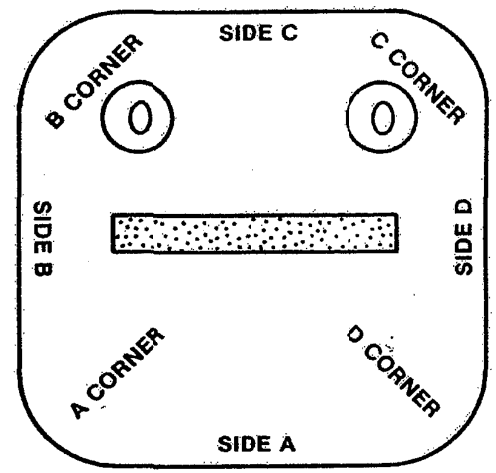
A uniform method of identifying the sides of the capacitor was established as specified in figure 3. Throughout this report, mention will be made to the reference position. Referring to figure 3, the reference position in the case of all tests except the knock test is that position of the capacitance standard resting upright on the lab table with Side A facing the operator. In the case of the knock tests, Side A faces the striking force (refer also to figure 2).

The long coaxial leads to the capacitor are used to allow for complete movement of the capacitor within the testing area as needed. The capacitor in all tests is connected to the bridge with the capacitance standard selected using Table 1 and in accordance with NBS procedures outlined in references (3), (4), and (5). All measurements start with the capacitor in the reference position and a return to the reference position after all movements associated with a particular test are accomplished.



(OPERATOR FACES)

TOP VIEW LOOKING DOWN



REFERENCE POINTS
FOR ALL MEASUREMENTS

FIGURE 3 REFERENCE POINTS - ALL TESTS

The long leads to the unit under test do not affect the accuracy of these measurements because only changes from the initial values are significant.

6. Connector Test

This test was devised to detect several common problems experienced with capacitors received for calibration at the NBS. Such problems are not necessarily related to transportation effects. Many standards arrive with loose connectors, loose connector inner conductors, or broken or damaged connector parts; for example, a leaf may be missing from the inner conductor of the GenRad 874 connectors, those most commonly used.

Repairs made at the user's lab have been found to create significant problems due, particularly, to improper soldering techniques. Unacceptably high or unstable conductances are often the result of cracked or cold solder joints at the inner pins of the connectors or at points of connection to the capacitor; likewise such faults may be associated with a loose inner conductor in either or both connectors. Modifications of the unit often lead to similar problems (6).

The procedure to determine if a connector defect exists is to apply a gentle force in a rotary fashion to each lead connector. The bridge must be balanced prior to this test. Any changes in capacitance or conductance are noted. Then, with the source oscillator voltage to the bridge off (to avoid transients in the bridge circuits), each connector is disconnected and then reconnected. Repeat, recording any difference observed. Changes greater than 0.05 ppm capacitance or 10^{-5} micromhos conductance are cause for concern. If a problem is apparent, check the points mentioned above to see if improvement can be achieved. In some cases, the rotation procedure will improve the readings without doing anything to the connector; this suggests dirt or oxidation on the connector surfaces or one of the other problems mentioned earlier. In such cases, the test should be repeated in an effort to obtain consistent results.

7. Orientation Test

This test is a good indicator of looseness in the web assembly (refer to figure 4), the case components, and possible problems within the sealed capacitor assembly.

The most frequent fault detected is a loose web assembly (refer to figure 4). Web assembly screws loose by one or more turns have been found to cause changes of several tenths of a part per million. Defects within the sealed capacitor, such as strains and mechanical displacement of the capacitor plates, may also be detected (6).

The procedure for this test is quite simple. The test capacitor is first placed with Side A facing the operator (refer to figure 3) and the capacitance bridge is balanced. This is the

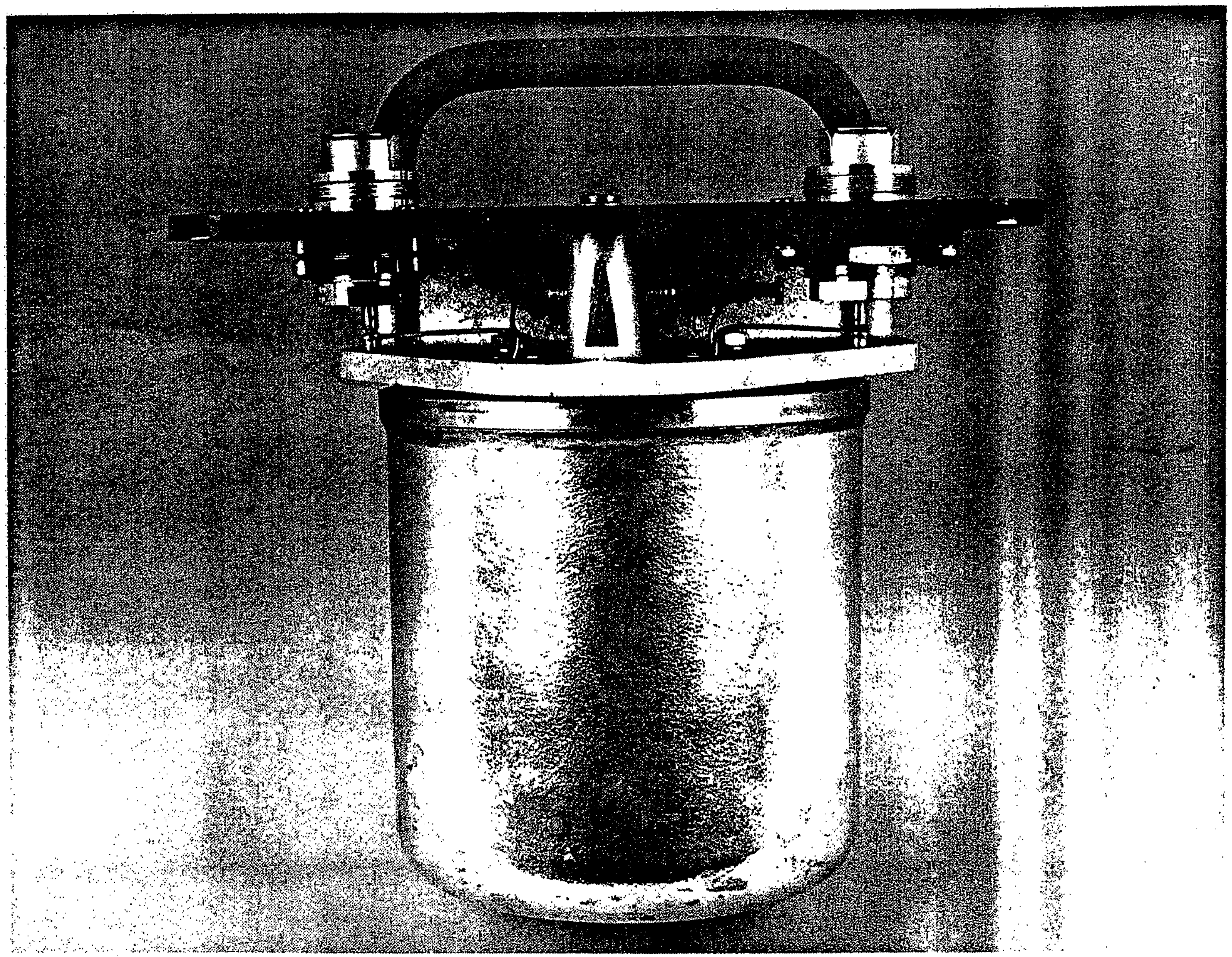


Figure 4. View showing web assembly.

reference position. Then the capacitor is moved from the upright position to a position of rest on Side A (refer to figure 5), the bridge rebalanced, and the capacitance value recorded. Without bringing the capacitor to the upright position, it is turned successively to positions of rest on Sides B, C, and D, the capacitance value for each position being recorded. After capacitance values for positions on all sides have been measured, the capacitor is returned to the upright position facing Side A (reference position) and a final measurement is made. The last reading, identified as ref2, is used to check the first (ref1) for drift (ref1-ref2=drift). Should the difference between the reference value and the value associated with any position be greater than ten ppm, the test should be repeated to determine whether or not the change is consistent or erratic. Two or more tests are desirable to reduce the possibility of a reading or recording error. Always use the last reference point in a series of measurements. If the capacitance value changes are not consistent from test to test, it is advisable to check the capacitor for defects such as loose screws, nuts, etc., including, in particular, those associated with the trimmer capacitor contained inside the outer enclosure and adjacent to the sealed capacitor assembly.

As indicated earlier, capacitors supplied from two different sources were evaluated. In the case of the models involved, the manufacturer's published specifications for maximum capacity changes under the conditions of the tests ranged from 1 ppm to 10 ppm. Changes greater than manufacturer's published specifications were considered as evidence of a defective capacitor.

8. Small Angle Test

This test was originally done for changes from zero to one, zero to two, and zero to three degrees. However, this series of tests was time consuming, and a single test for a change from zero to three degrees was found to be just as useful. The angle of three degrees was selected as the worst case by measuring a number of laboratory tables and finding that surfaces are usually within plus or minus two degrees of the horizontal. The change in capacitance due to small changes in angle of tilt is generally found to be a linear function of the angle within the zero to three degree limits. A worst-case acceptable value of 0.2 ppm per degree of angle change has been established for capacitors in satisfactory condition [1].

The procedure for this test is not difficult. However, the placement of the capacitor, adjustment of the elevated table, and provisions to avoid movement of the laboratory table or the elevated table are all important for consistent results (refer to figure 6). Be sure the adjustable table is horizontal (zero degrees). Then place the capacitor in the center of the tiltable plate on the adjustable table upright with Side A facing the operator. The measured capacitance under these conditions becomes the reference value and should be recorded as such. Use the adjustable knob to increase the angle to three degrees or, alter-

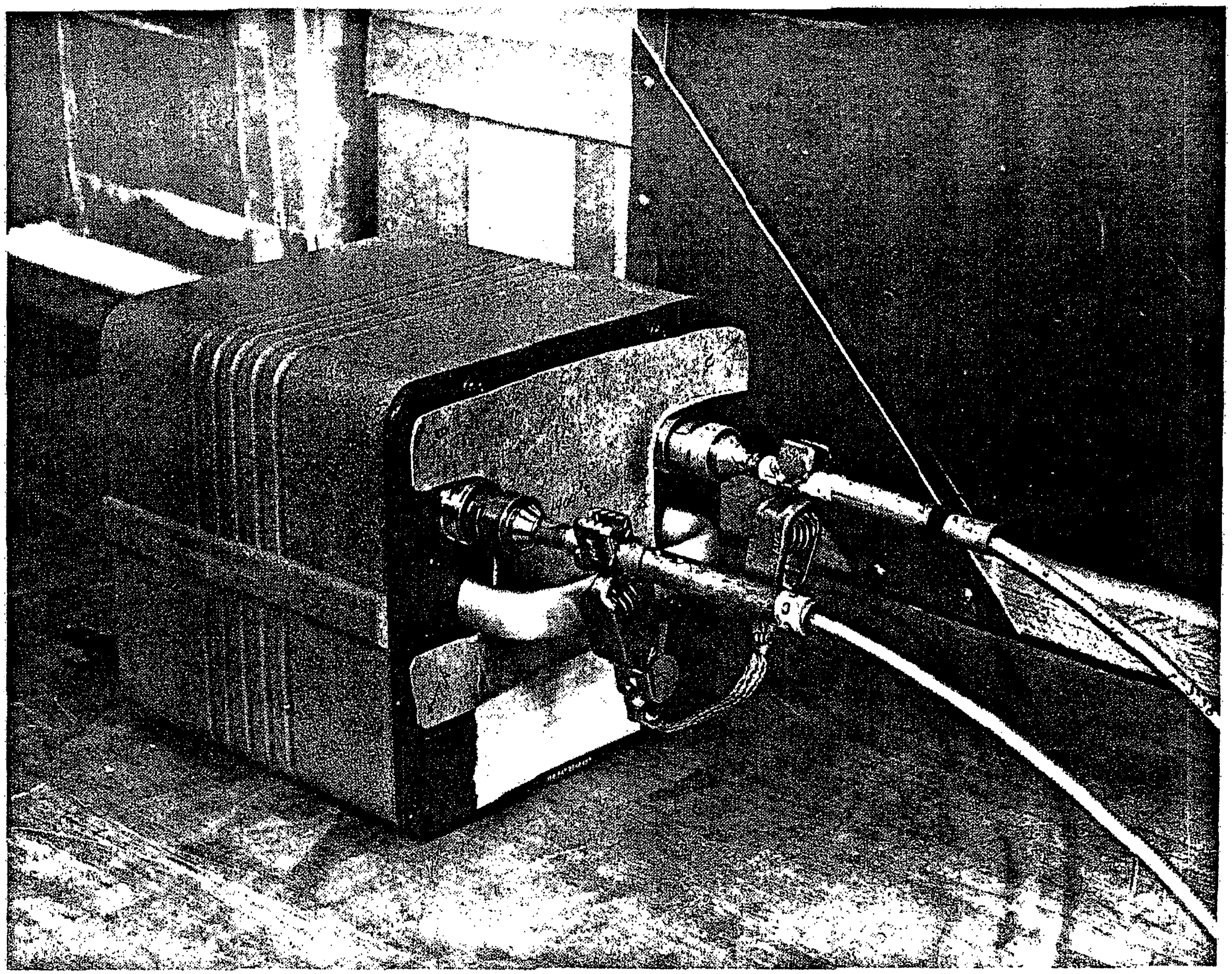


Figure 5. Orientation test - side A.

nately, use the special block made for three degrees, located securely in a suitable slot to avoid error in the elevation of the table. (Refer to figure 6). Measure the capacitance values with Sides A, B, C, and D facing the operator. Differences greater than 0.2 ppm between the reference value and the value associated with any other position indicates that the test should be repeated. If the results of a second series of measurements are similar to those of the first run, the changes probably reflect a characteristic of the particular capacitor. If the test is repeated, and the results are significantly different from those of the first test, subtract the smallest change from the largest change and record one half the result; this value should not be greater than 0.2 ppm. If it is larger, check for looseness in the web assembly.

9. <u>Tilt Test</u>

The tilt test (rotation through angles of 90 degrees, 180 degrees and return) serves several purposes. The geometry of parallel plate capacitors is such that movement of the plates will cause changes in capacitance. For example, shifting of the capacitor plates by only a few thousandths of an inch will cause changes ranging from a few tenths of a part per million to several parts per million. If all accessible fasteners holding the capacitor to the web assembly are tight and a sudden change in capacitance can be detected upon tilting and it does not disappear within plus or minus 0.1 ppm when the capacitor is placed back in the upright position on the table, it may be assumed that a problem exists within the sealed capacitor assembly.

The testing procedure is as follows. First, place the capacitor in the reference position on the table with leads connected as in previous tests. Balance the capacitance bridge as usual. Then grasp the handle of the capacitor and by balancing the weight of the capacitor in the other hand (refer to figure 7), turn (gently) the capacitor to a position with Side A in the horizontal plane. Note any erratic changes of the detector reading as you place the capacitor in the upright position on the table. Record any change observed. Repeat the test for Sides B, C, and D. Finally, repeat the test for the inverted position (refer to Figure 8). Grasp the capacitor and turn it upside down again observing the detector for changes as you return the capacitor to the normal orientation and place it back on the table.

Changes greater than 0.2 ppm between any two measurements of the capacitance of the upright capacitor indicate the possibility of a problem and the test should be repeated at least once. If the change is greater than 0.2 ppm, and consistent with the previous test, the test may be considered to reflect a characteristic of the capacitor. If changes during a second test are significant and do not repeat the results of the first test, check for looseness in the web assembly and capacitor assembly mounting parts. In the worst case, you might hear a distinct

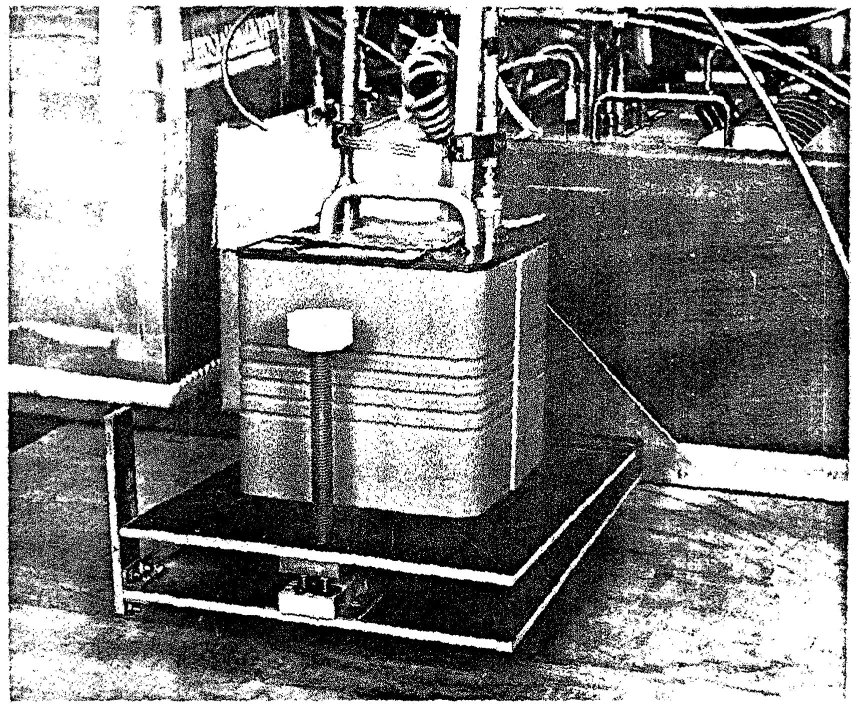


Figure 6. Angle test - special block for 3 degrees in place.

"clunk" as you invert the capacitor indicating that the capacitor assembly within the case will probably be found to be loose.

Visual observation of the detector during this test is essential. Erratic behavior, indicated by a sudden change in the detector zero point, may be evidence of problems such as movement within the capacitor. This should be recorded to determine, in the future, if the quality of the capacitor degrades with time. It is also suggested that such a capacitor be calibrated more frequently as behavior of this nature is generally a sign of impending deterioration. Before reaching a conclusion that the capacitor is faulty, be sure to check all fasteners previously mentioned as well as connection points and cables. In many cases, a correctable fault can be eliminated.

10. <u>Knock Soft Test</u>

The mechanical shock in the knock soft test is approximately equal to a mild, wrist-action motion of one's hand against the side of the capacitor. The test is a controlled impact of a soft rubber-tipped hammer swung, in the vertical plane, from a position of 45 degrees. The hammer strikes the test unit on a side, just below the horizontal plane of the top surface, and midway between adjacent sides.

This test may reveal several conditions. For example, defects within the sealed capacitor enclosure, or looseness of fasteners in the web assembly of the capacitor, may be responsible for shock-induced changes of capacitance.

During transit, the capacitor is generally subjected to larger mechanical forces than this test will produce. However, small impulsive forces often create more noticeable changes within a capacitor than larger, less impulsive forces. This test is intended to simulate a typical impulsive force that a well-packed capacitor may receive during handling in transit. There are no specified manufacturers' limits for such shocks.

For the test, use the stand with the soft tip end of the hammer head toward the face of Side A of the capacitor. Balance the bridge and record the reading. This capacitance value is the reference value. The hammer is then drawn back to the 45 degree position and released to strike the capacitor (refer to Appendix 2, Figures 2 and 4). However, it is not allowed to strike a second time following rebound. Again the capacitance value is recorded. The capacitor is moved to position A Corner (refer to figure 3) for a hammer strike. The measurement is repeated through all sides and corners in the order: Side A, Corner A, Side B, Corner B, Side C, Corner C, Side D, Corner D.

If changes are greater than 0.2 ppm between any two tests in this series, it is suggested that the series be repeated. If the relative changes between a first series and a second series is noted to be approximately the same, subsequent tests are not necessary.

11. <u>Knock Hard Test</u>

This test is similar to the knock soft test. The differences are that the hammer swing is limited to fifteen degrees and the hard tipped head strikes the capacitor. The object of this test is to simulate shocks received by the test capacitor when, in being lifted from a work bench, it accidentally strikes another object. Mechanical shock in transit may, under some conditions, be similar to this type of shock. This test is particularly effective for detecting problems associated with the trimmer capacitor.

Changes larger than 0.2 ppm should be recorded, particularly when two sets of readings do not repeat. Changes greater than 0.5 ppm are cause for concern and the capacitor should be carefully checked for correctable defects. If there are no loose components, the excesssive capacitance change may be a result of stress changes within the sealed capacitor enclosure.

12. <u>Drop Test</u>

The drop test was devised to simulate a shock which may occur in service, for example, due to a drop from the hand to a table surface. It may also simulate, to some extent, the dropping of the standard in its shipping container during handling in transit. Short-duration forces in the vertical direction may cause various movements of plates or support rods. Intermittent electrical shorts between plates may sometimes be found using this method.

Testing the unknown capacitor requires a block of wood having measurements of 3.8 cm (1.5 inches) x 8.9 cm (3.5 inches) and from 10 to 15 cm (4-6 inches) long (refer to figure 9). Balance the capacitance bridge with the capacitor normally resting on the table, being sure that all four feet of the capacitor are in contact with table surface. Then place the block of wood under Side A (smallest dimension vertical) and carefully, but swiftly, pull out the block. After the block of wood has been removed and the capacitor has struck the table, record any changes in capacitance value. The test is repeated raising each side of the capacitor sequentially (Side A, B, C, and D). Changes greater than 0.2 ppm between any two capacitance values, or between the reference value and any other value should be recorded. Changes greater than 1 ppm indicate the possibility of a problem capacitor.

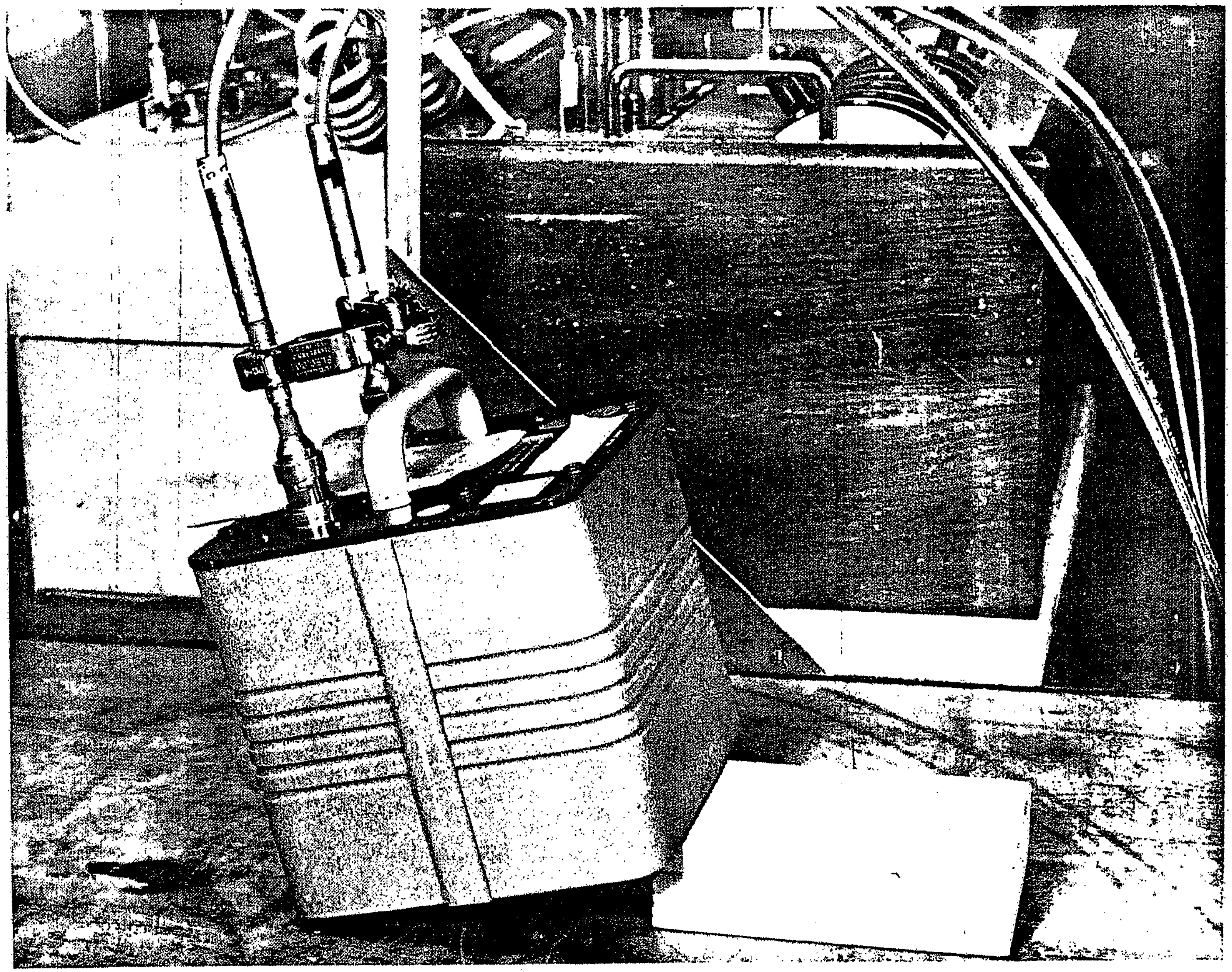


Figure 9. Set-up for simulated drop test.

13. General Considerations

All of the tests described in this document should be performed in a systematic manner. No test should be discontinued until all specified sides, corners, etc. have been included. The specified order of tests, connectors, orientation, small angle, tilt, knock soft, knock hard, and drop test should be followed to eliminate possible confusion in comparing results with those of earlier or later tests. This order was determined to give the most reproducible results. There is one caution that should be mentioned. If any fasteners are suspected of being loose, either tighten all fasteners before the handling test is undertaken, or wait until all tests are completed. Otherwise, it will not be possible to know if the repairs caused or cured the problem(s).

It is not necessary to complete a series of tests in one day; it is only important that the tests be done in the proper sequence. This is the only way to obtain a repeatable characterization of the standard.

Capacitors determined to be faulty should be retested before any repairs are attempted in order to eliminate the possibility of other factors such as improper hook-up, faulty electrical leads, bridge problems, or faulty connections within the test system being used.

The use of two reference standards, having known characteristics, to which the unit under test is compared, one during the first half of the test series and the other during the second half, may help reveal problems external to the test capacitor. Such problems might include intermittent faults in a reference capacitor, improper hook-up, bridge malfunction, faulty leads, or faulty connectors.

14. Data Reduction

The data for any of the test series described in the previous sections of this document may be represented by a string as follows:

ref, rdg_1 rdg_2 .... rdg_n,

where ref=initial reference value which appears only at the beginning of a string for all positions to be tested, and rdg_i=reading for a particular side or corner.

Successive differences or changes would then be as follows:

$$\begin{aligned} dif_1 &= rdg_1 - ref_1 \\ dif_2 &= rdg_2 - rdg_1 \\ dif_3 &= rdg_3 - rdg_2 \\ &\vdots \\ dif_n &= rdg_n - rdg_{n-1}, \end{aligned}$$

where dif = difference, rdg_i = reading at position i, and ref = reference.

The range between any two values is used for two reasons. In the first place, most laboratories only need to know the maximum change expected. In the second place, if changes were nearly equal but opposite in sign, the average would underestimate possible changes. Changes noted for each side or corner in a string usually will not be randomly distributed, particularly when significant changes are experienced.

For the tests listed, the following data should be obtained:

ORIENTATION: Minimum of six data points required - ref1, Side A, Side B, Side C, Side D, ref2

ANGLE 3 DEGREES: Minimum of six data points required - ref_1, Side A, Side B, Side C, Side D, ref_2

TILT: Minimum of six data points required - ref, side A, side B, Side C, Side D, upside down, rightside up

KNOCK SOFT OR HARD TEST: Minimum of nine data points required - ref, Side A, Corner A, Side B, Corner B, Side C, Corner C, Side D, Corner D

In the orientation and angle tests, drift can be determined from the difference between the first reference and last reference in a given string. If the test is completed with minimal time between measurements (less than a half hour), drift in excess of 0.2 ppm should be recorded. Most excessive drift will be observed during the first few minutes of testing. In some cases, drift may continue for several minutes or as long as a half hour. Such drift may be caused by changes in temperature of the capacitor under test or changes in temperature of the standard used as the reference. While the latter may be placed in a lag box to reduce the effects of rapid temperature fluctuations, it may not be practical to do so for the capacitor being tested. Therefore, these tests should each be carried out rapidly to minimize temperature-created anomalies in the data (which one would have a difficult time sorting out from the effects of defects) and take place in a relatively well-controlled room.

Except for the results of the orientation test, the magnitude of changes caused by handling tests should be included in the uncertainty of calibration results as a systematic error. This is particularly important if any of the changes are greater than 0.5 ppm. In the case of capacitance standards which are not kept continuously within the metrology laboratory or are otherwise exposed to unusual handling conditions, experience at NBS suggests that the calibration uncertainty should be increased by the addition of half the largest change induced by the handling tests described in this document [1].

The stresses described in this document are believed to be small compared to those that are encountered in normal shipping and handling; therefore, unusual effects due to shipping should be determined by using the results of control measurements made in the user laboratory before and after shipping in addition to the results of these tests at NBS.

15. Unusual Problems

Gas dielectric capacitors have two sources of capacitance change which are not repairable by the user; in the first place, all gas dielectric capacitors manufactured in the United States use a trimmer capacitor to bring the value of the capacitor close to its nominal value. Many users adjust this capacitor to meet specific needs. Two types of trimmers are in use, one having an adjustable core and the other having interleaved plates similar to a radio tuning capacitor. The plate type is rarely found to be a problem unless it becomes loose. Since this type is generally exposed within the capacitor housing, a loose part, such as a nut or screw, falling between the blades of the trimmer capacitor may cause an electrical short or mechanical damage to the plates. Such faults may cause capacitance changes of greater than 100 ppm. Changes in placement of the leads to the trimmer may also affect the capacitance by several ppm in either direction without any change in the trimmer adjustment.

The coaxial adjustable-core type of capacitor trimmer has been known to short, or worse, fall apart due to extreme abuse in transit. If there is a possibility of an electrical short, the trimmer must be replaced because excessive current will be drawn through the measuring system. Malfunction of the trimmer may cause a capacitance change of several hundred ppm.

Removal of either type of trimmer will result in capacitance changes of up to 300 ppm (determined for the capacitors selected for the NBS portable transport box). If such departures from nominal value are acceptable, it is suggested that the trimmer capacitor be removed to eliminate a possible cause of instability.

A second, less frequent, problem involves hermetic seal leakage. The hermetic seals of capacitors manufactured in the United States are generally trouble free unless undue pressure is applied on the electrical feed-through connection points or they are overheated. Cracked seals are not common; however, if this is suspected, temperature cycling will reveal the fault. Cooling to freezing followed by warming to approximately forty degrees Celsius and returning to lab temperature should be sufficient to verify seal leakage. A capacitor that is cycled will not retrace to the previous value within the tolerance stated by the manufacturer unless the seals are intact. There may be problems within the sealed capacitor other than those associated with the seals. However, any capacitor that cannot be cycled without significant changes should not be considered satisfactory as a working standard.

16. Conclusion

A review of the graphs for the various test procedures will disclose the utility of handling tests described in this document. The overall results of a number of such tests conducted at NBS are summarized in table 2, following:

Table 2. Summation of tests

TEST	ACCEPTABLE LIMITS* (PPM)	% FAILED
Orientation	10	23
Angle 3 Degrees	0.2	48
Tilt	0.2	5
Knock Soft	0.2	14
Knock Hard	0.2	13
Drop	0.2	14

*Acceptable limits excluding orientation test for which one half the largest change in any test should be added to the uncertainty of calibration.

The tables and graphs (Appendix 1) in this document are derived from the results of tests carried out on 200 capacitors during the period 1972-78. The method of evaluation involved collection of data from all capacitors received for testing the first time in order to establish a basis unbiased by the selection criteria and to reflect a good cross-section of all capacitors received. Data are selected randomly from all capacitors received for test in order to avoid disclosure of differences between the products of different manufacturers. Data from succeeding years were also selected randomly for capacitors not used in previous data evaluations in order to obtain an overall balance.

Data from the first year of testing were compared with data from succeeding years with very convincing results. In more than 80% of the cases compared, the results of the capacitors repeated to within 0.2 ppm of those from the previous year for each particular test. Most capacitors with changes greater than 0.2 ppm had been subjected to rough treatment. For fewer than 10% there was no discernible reason for the changes noted.

Referring to the summary of tests, it is apparent that the orientation and three degree angle tests were failed more often than the other tests. If a capacitor shows poor results on the tilt test, the problem can, in principle, be overcome by using a level table. In the case of the orientation problem, there is not much that can be done other than use the capacitor in the upright position. It should be recognized that excessive changes during these tests suggest a lack of mechanical integrity within the standard capacitor and reliabilty during service is open to question.

It will be noted that there is no graph in Appendix 1 for the connector test. Generally, the changes during this test are small and when a problem with a connector is corrected, there is generally no remaining concern.

17. Additional Observations

The care with which a gas dielectric capacitor is packed for shipping can, to a large extent, determine its useful life. Manufacturers in the United States ship standard capacitors in protective reusable containers, which should also be placed in an outer box containing at least 10 cm (4 inches) of shock-absorbing material on all sides for added protection.

Exposure of the capacitor to abnormal temperatures, such as those found in the trunk of a car on a hot day, should be avoided. The time for the capacitor to stabilize after being exposed to excessively low or high temperatures depends on the design of the capacitor. A similar consideration applies following a long period of storage with the capacitor resting on a side; a period of recovery in the normal upright position is necessary before its use or before calibration at NBS.

Checking all screws, nuts, etc., for looseness before the capacitor is shipped for calibration will reduce the possibility of damage due to the movement of parts during transit. Loose connectors should be properly positioned and tightened before tests are started.

Handling the capacitor in the laboratory or field is as important as care in shipping if long term stability is essential. Capacitors receiving rough treatment, such as impacts against other equipment or furniture, may be damaged in terms of loosened parts or more serious mechanical changes.

It is important to document values and abnormal changes found in the handling tests. Both can guide the user in avoiding problems and removing from service a faulty capacitor; many hours of needless measurements can, thereby, be saved.

All maintenance and repairs should be performed after completing the series of tests described in this document unless a definite problem is detected. In this way, problems discovered during tests may be evaluated as correctable or otherwise identified as an intrinsic characteristic of the unit under test.

The material contained within this paper is intended to serve as a guide; it is not suggested that the problems discussed are the only problems the user will experience. However, the handling tests described have been found to disclose the most frequent problems encountered at NBS. All known causes of capacitance change should be documented fully and the capacitor should be monitored systematically if it is to be used at the five ppm level of uncertainty.

18. References

[1] Free, G. and Morrow, J., Transportable 1000 pF capacitance standard. Nat. Bur. Stand. (U.S.) Tech. Note 1162; 1982.

[2] Anderson, W. E., Davis, R.S., Petersens, O., and Moore, W. J. M., An International Comparison of High Voltage Capacitor Calibrtions, IEEE Trans. Power Appar. Syst. PAS-97(4), pp. 1217-1223 (1978).

[3] Thompson, A.M., The precise measurement of small capacitances. IRE Trans. Instrum. I-7(3-4):245-255; 1958 Dec.

[4] Cutkosky, R.D., Four-terminal pair network as precision admittance and impedance standards. IEEE Trns. Commun. Electron. 70:19-22, 1964 Jan.

[5] Homan, D. N., Application of coaxial chokes to a-c bridge circuits. J. Res. Nat. Bur. Stand. 72C(2):161-165; 1968 April-June.

[6] A highly stable reference standard capacitor. GR Experimenter. 37(8); 1963 August.

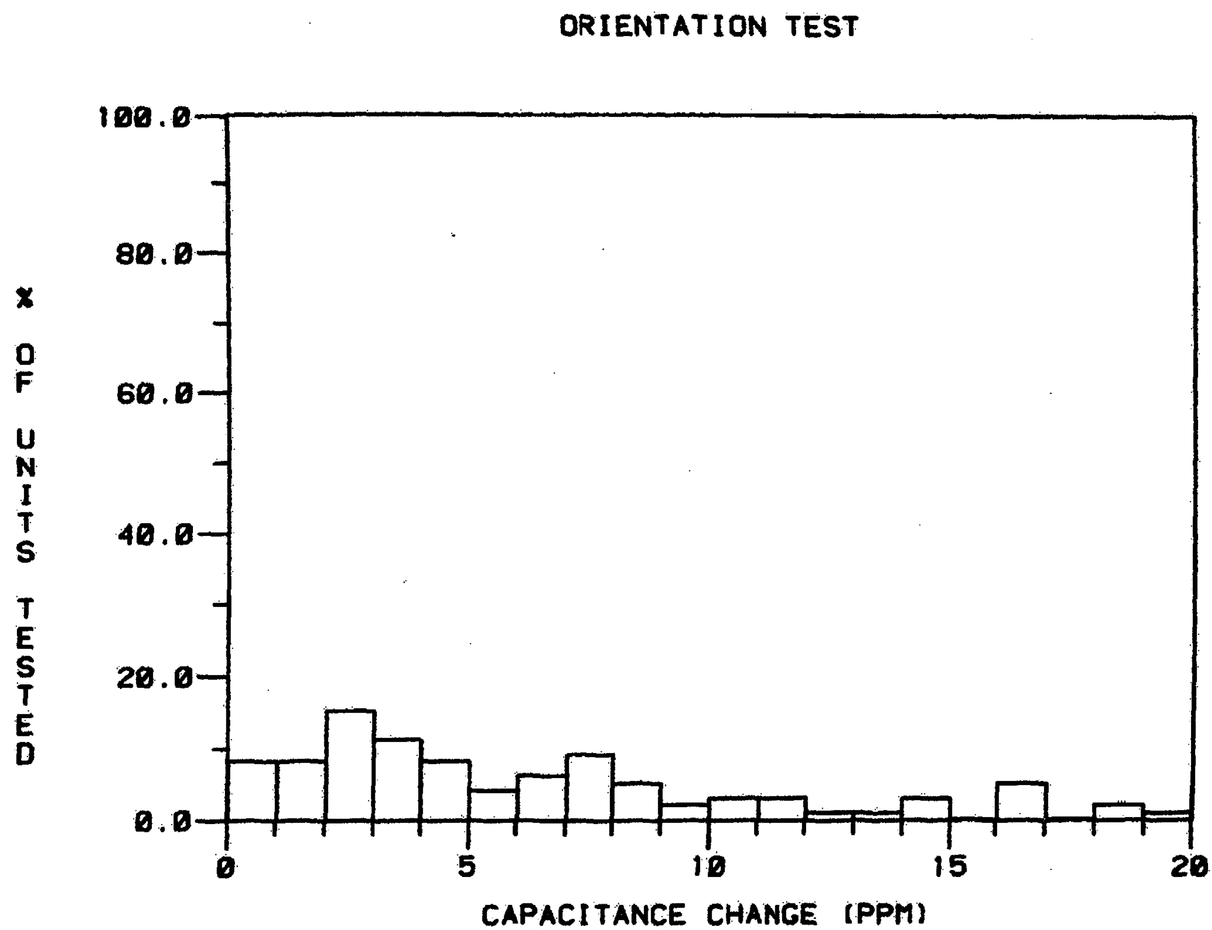
[7] Thoma, P., Absolute calorimetric determination of dielectric loss factors at = $10^4 s^{-1}$ and application to measurement of loss factors of standard capacitors at room temperature. IEEE Trans. Instrum. Meas. IM-29(4); 1980 Dec.

[8] McGregor, M. C., Hersh, J. F., Cutkosky, R.D., Harris, F. K., and Kotter, F. R., New apparatus at NBS for absolute capacitance measurements. IRE Trans. Instrum. I-7:253-261; 1958 Dec.

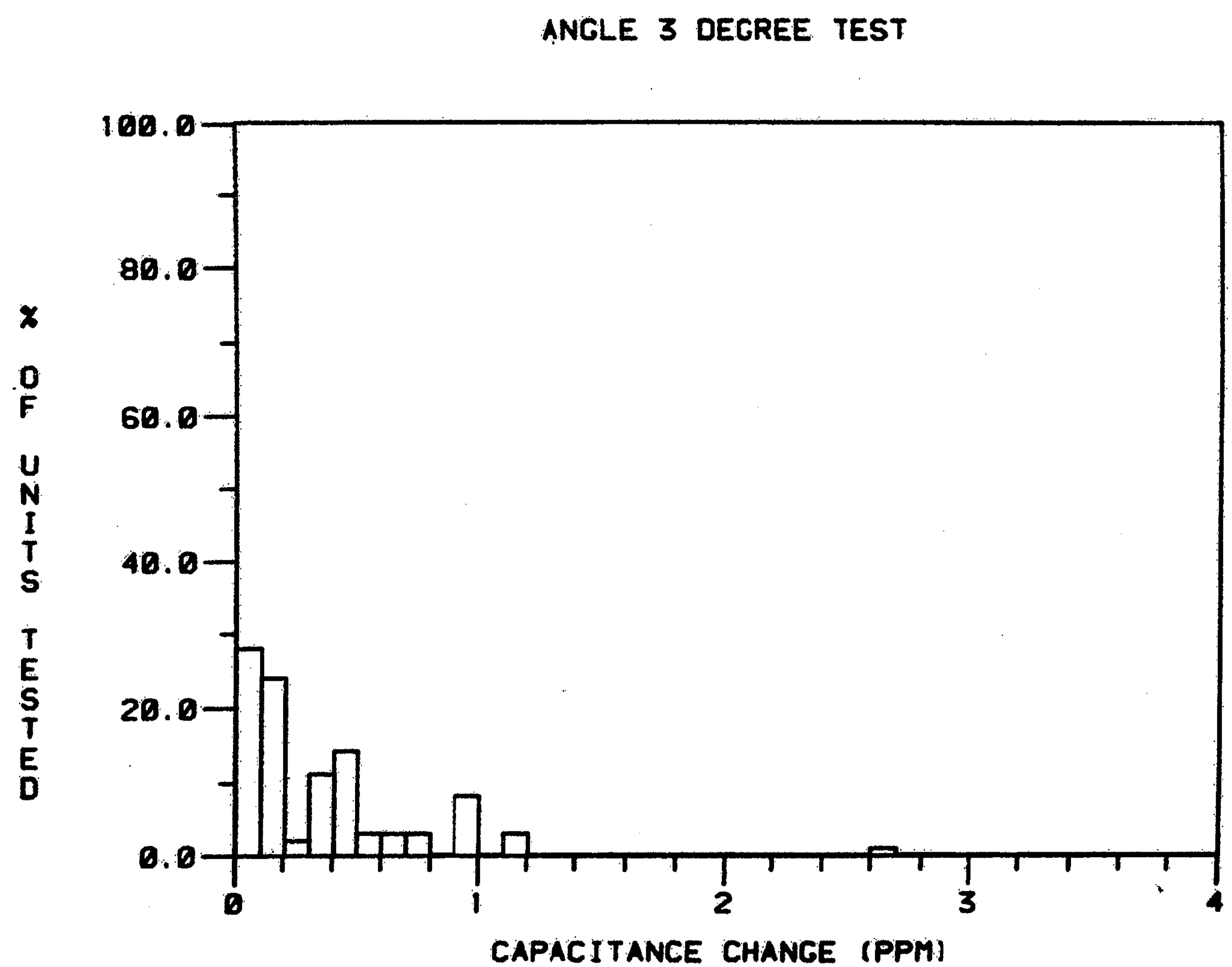
Appendix 1

Histograms of the Effects of Handling and Stability Tests on Standard Capacitors

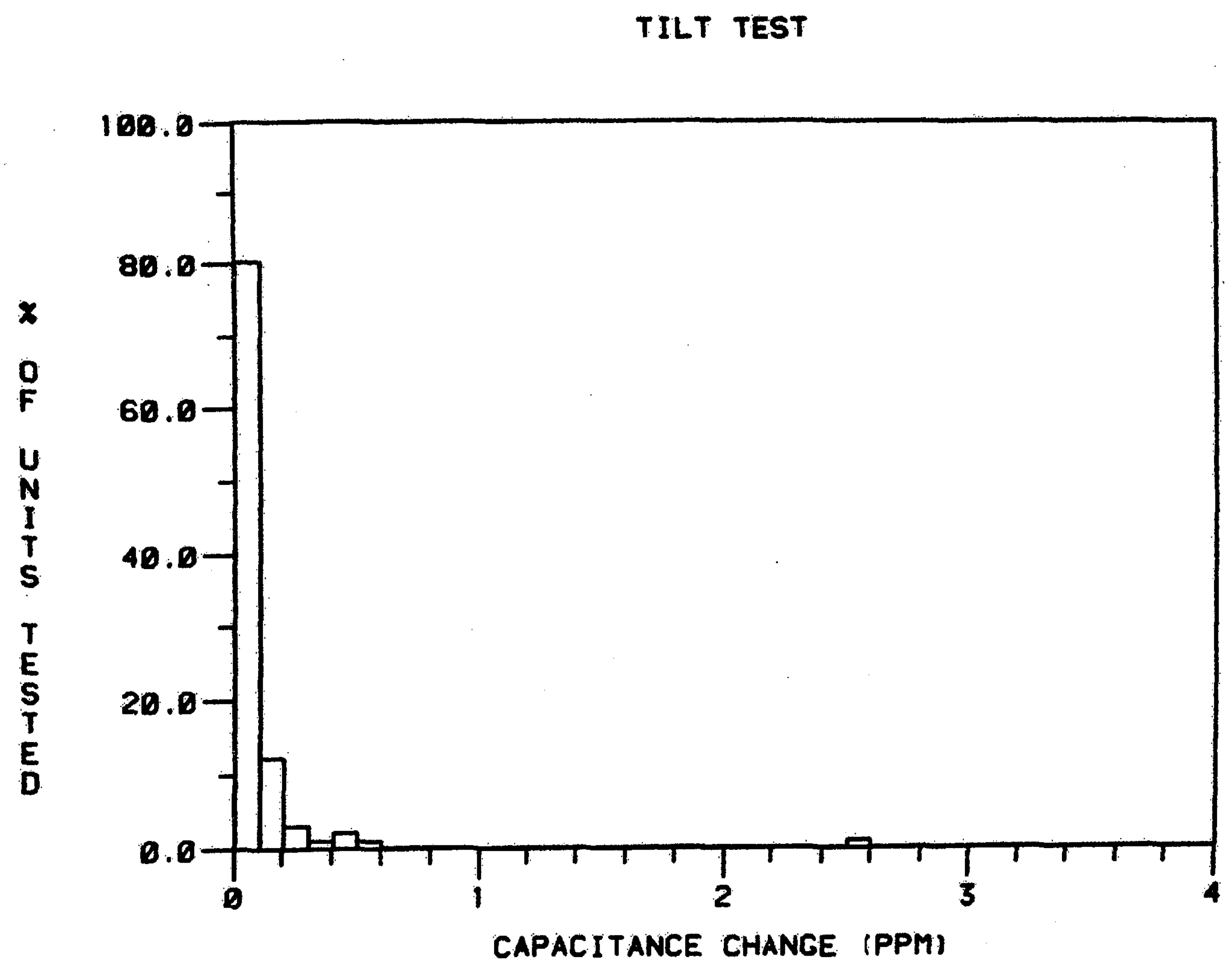
The following histograms are based upon the results of performing each of the Handling and Stability Tests on each capacitor of the test group. The maximum capacitance change value caused by a given test performed a number of times on each capacitor was used to determine the numbers of capacitors for which such change values fell within the ranges indicated in the histograms.



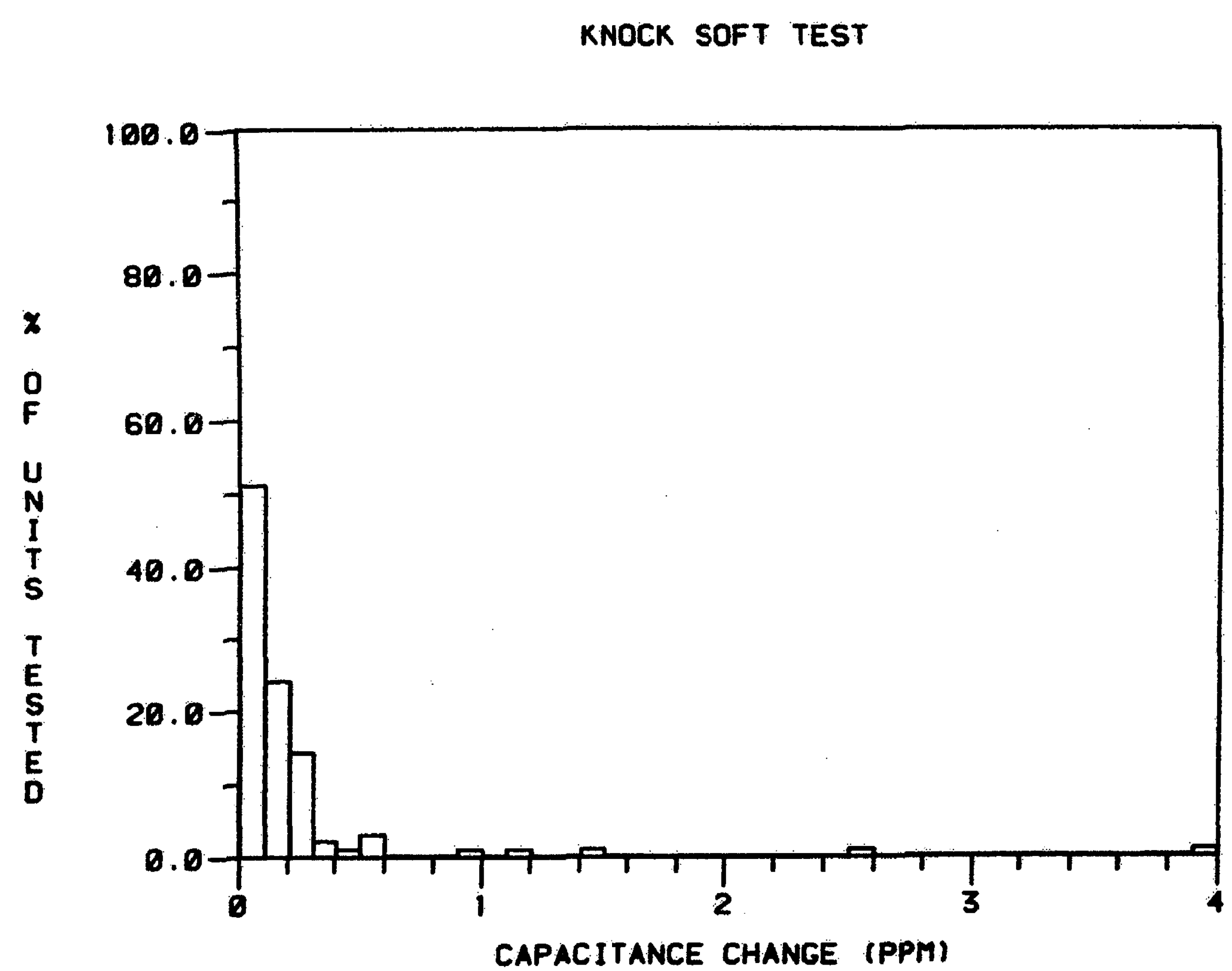
Appendix 1, Figure 1. Histogram of the fractional numbers of capacitors for which different values of maximum capacitance were caused by the Orientation Test.



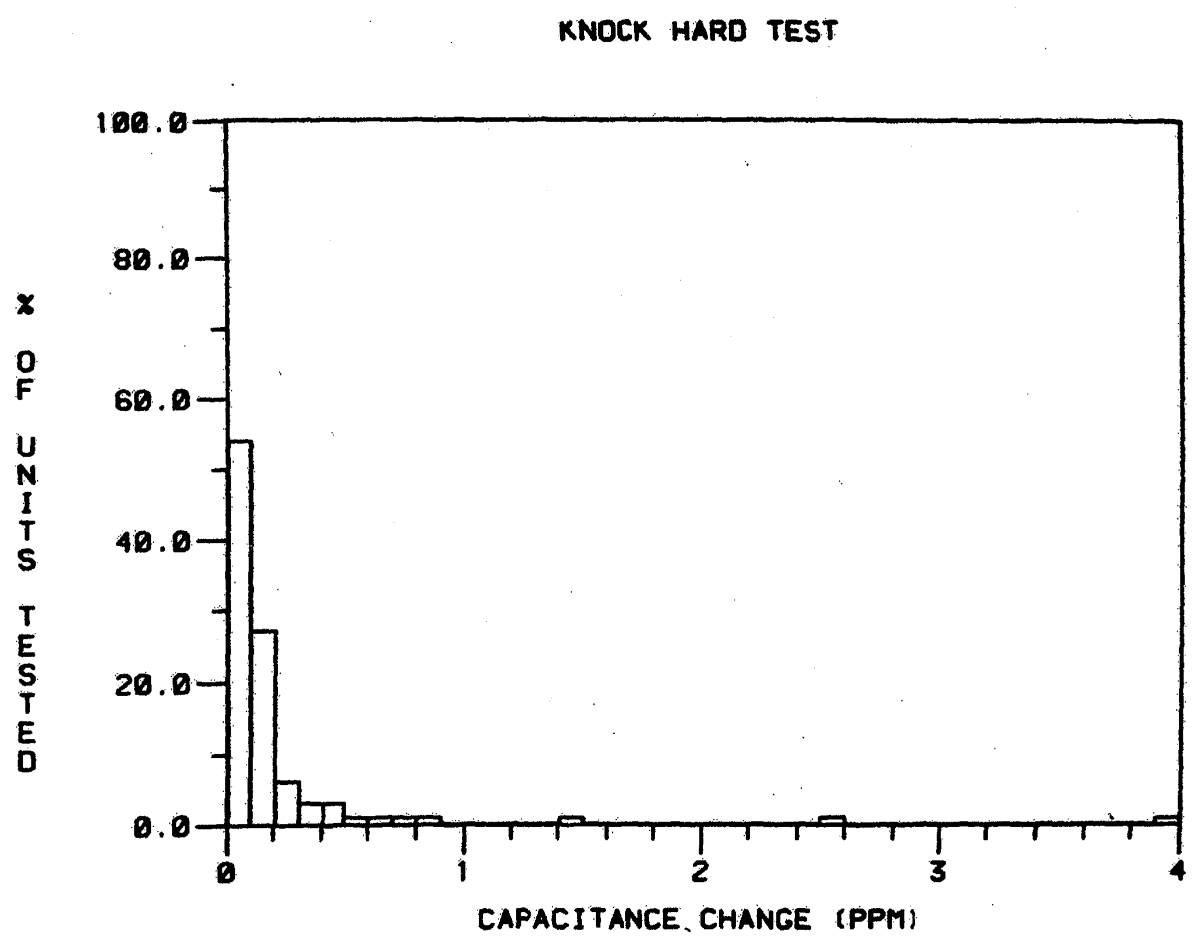
Appendix 1, Figure 2. Histogram of the fractional numbers of capacitors for which different values of maximum capacitance change were caused by the Angle 3 Degree Test.



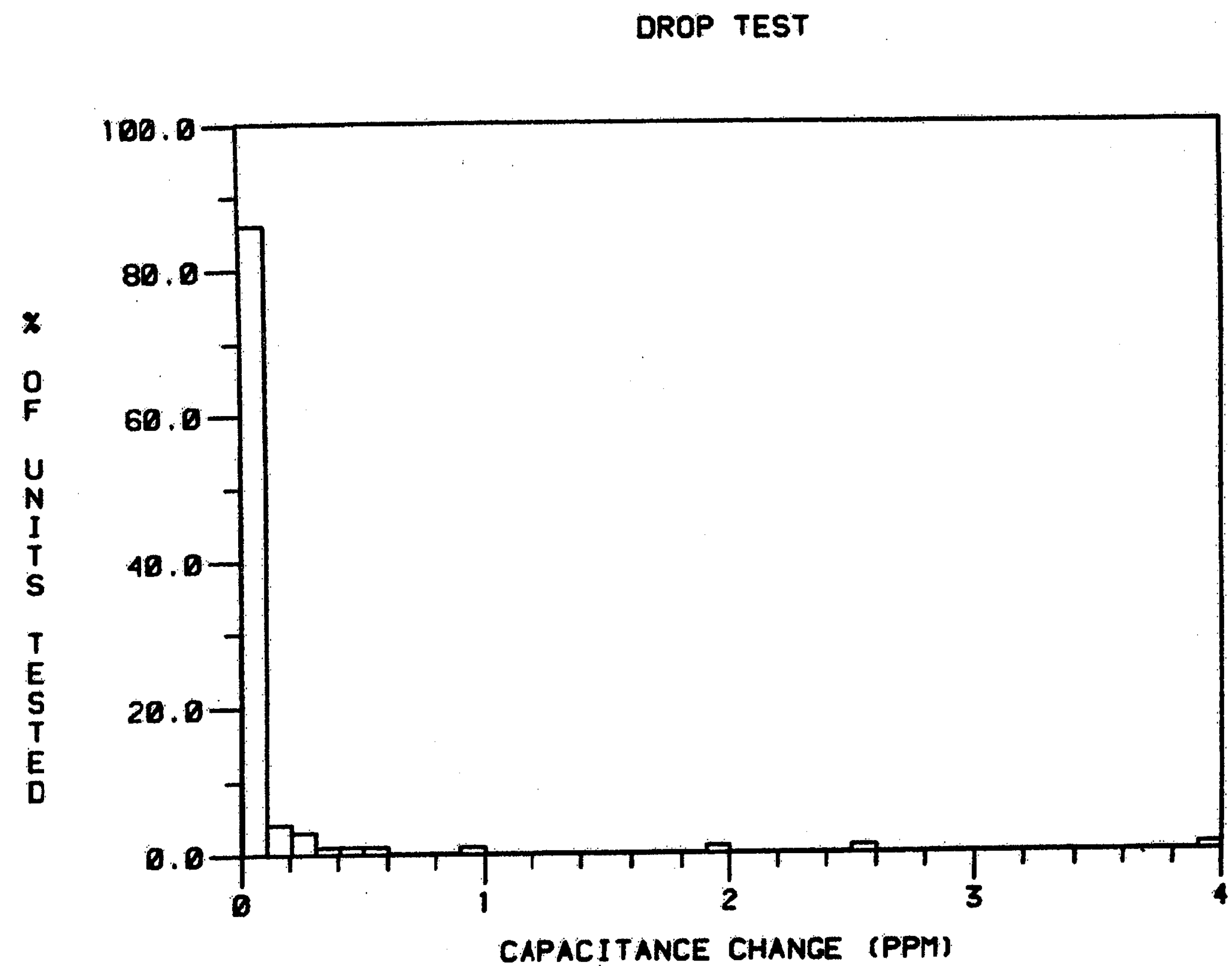
Appendix 1, Figure 3. Histogram of the fractional numbers of capacitors for which different values of maximum capacitance change were caused by the Tilt Test.



Appendix 1, Figure 4. Histogram of the fractional numbers of capacitors for which different values of maximum capacitance change were caused by the Knock Soft Test.



Appendix 1, Figure 5. Histogram of the fractional numbers of capacitors for which different values of maximum capacitance change were caused by the Knock Hard Test.



Appendix 1, Figure 6. Histogram of the fractional numbers of capacitors for which different values of maximum capacitance change were caused by the Drop Test.

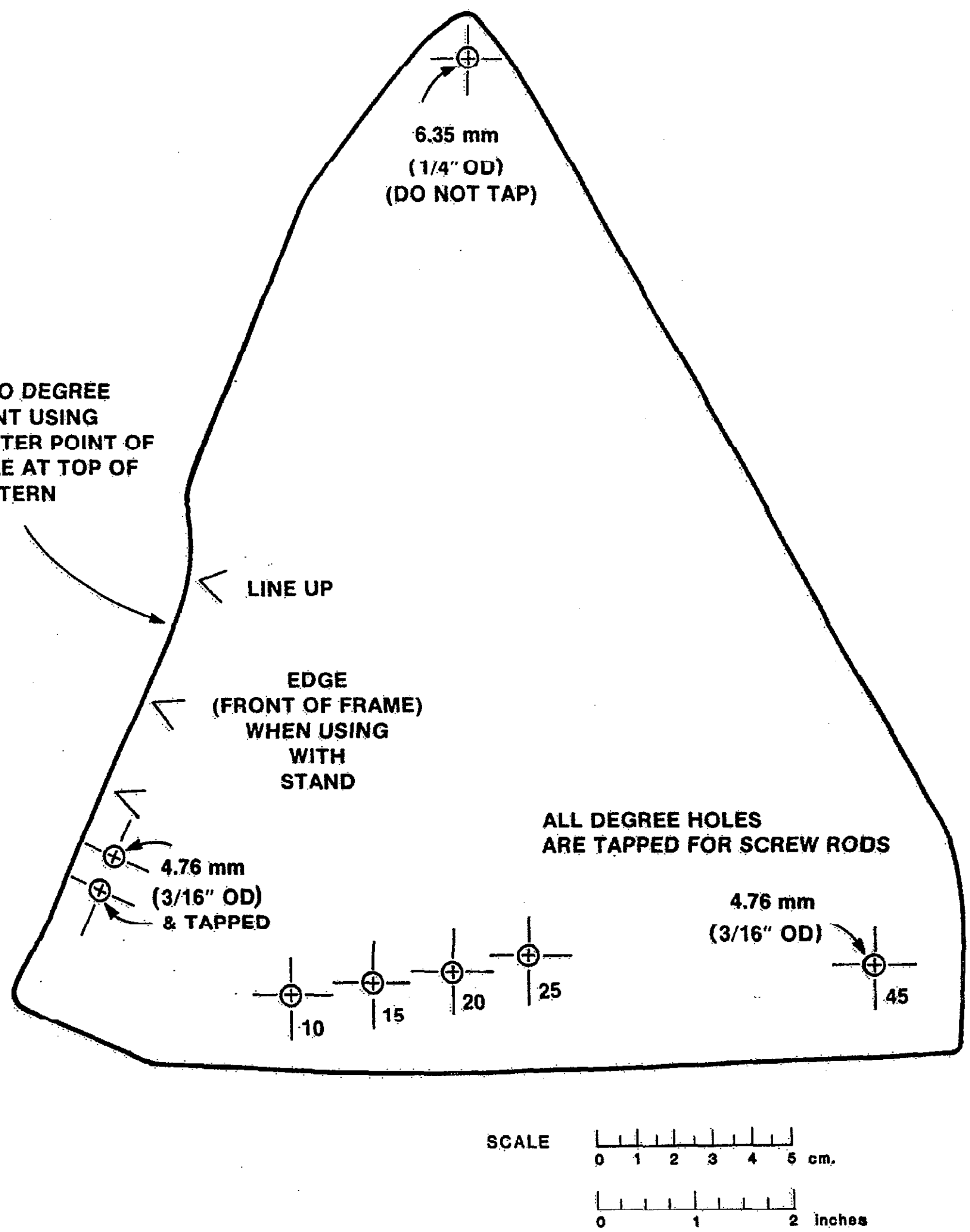
Appendix 2

Drawings of Test Apparatus

The following drawings represent the apparatus used at the National Bureau of Standards for the tests described in this publication. Dimensions are given in metric units and customary units used in the United States.

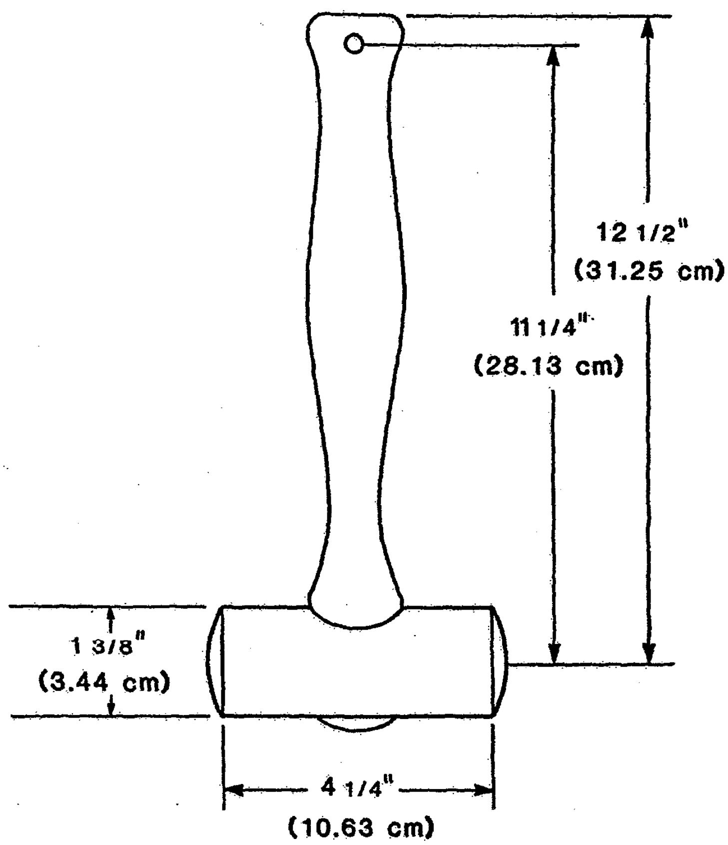
Appendix 2, Figure 1.

KNOCK STAND ANGLE PLATE PATTERN



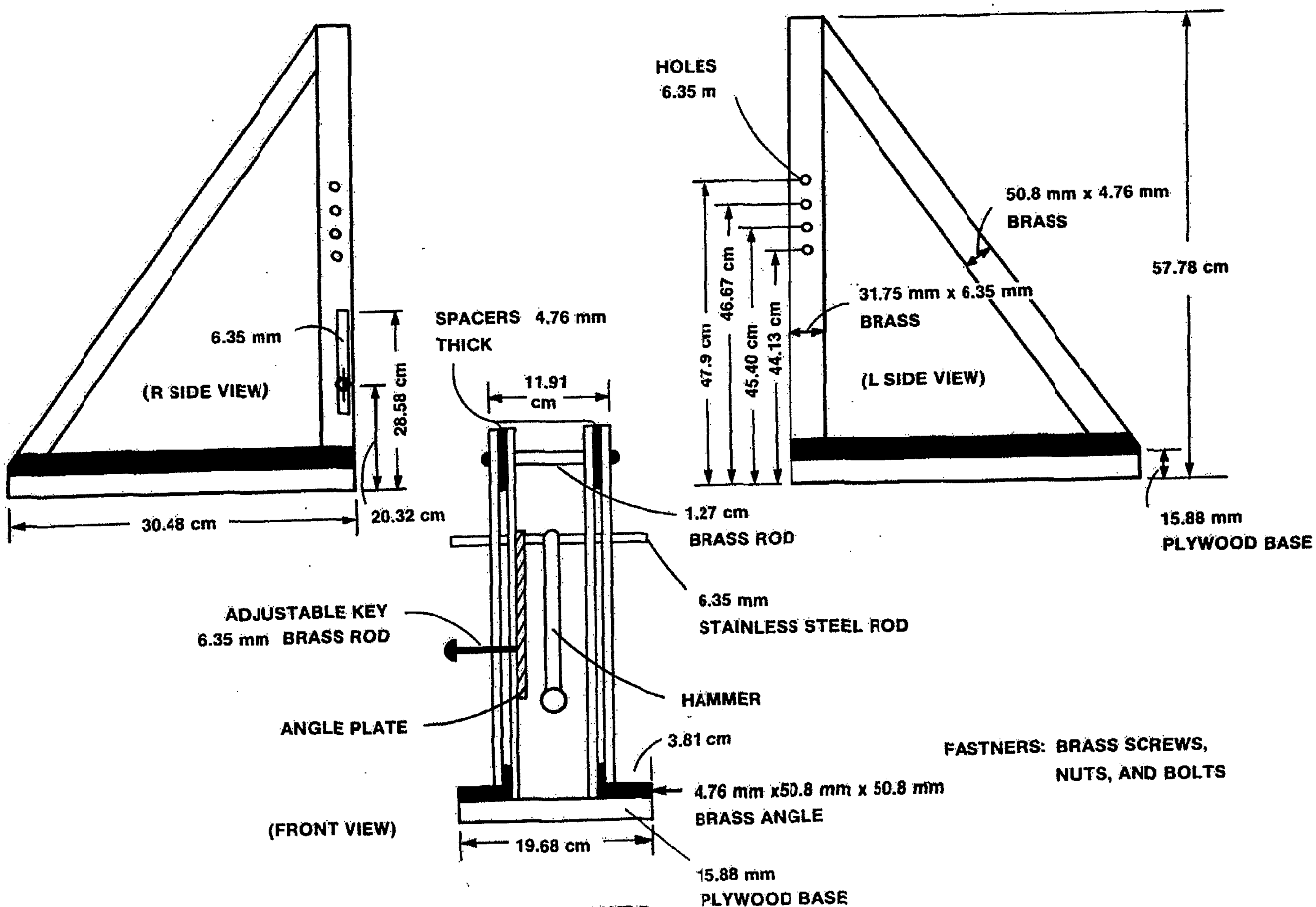
Appendix 2, Figure 2.
Hammer for use with Knock Stand (see following figure)

	grams	lbs.
HARD RUBBER HEAD	41.03	.09
SOFT RUBBER HEAD	46.70	.10
HAMMER–HEADS	441.14	.97
TOTAL Wt. OF HAMMER	528.87	1.16



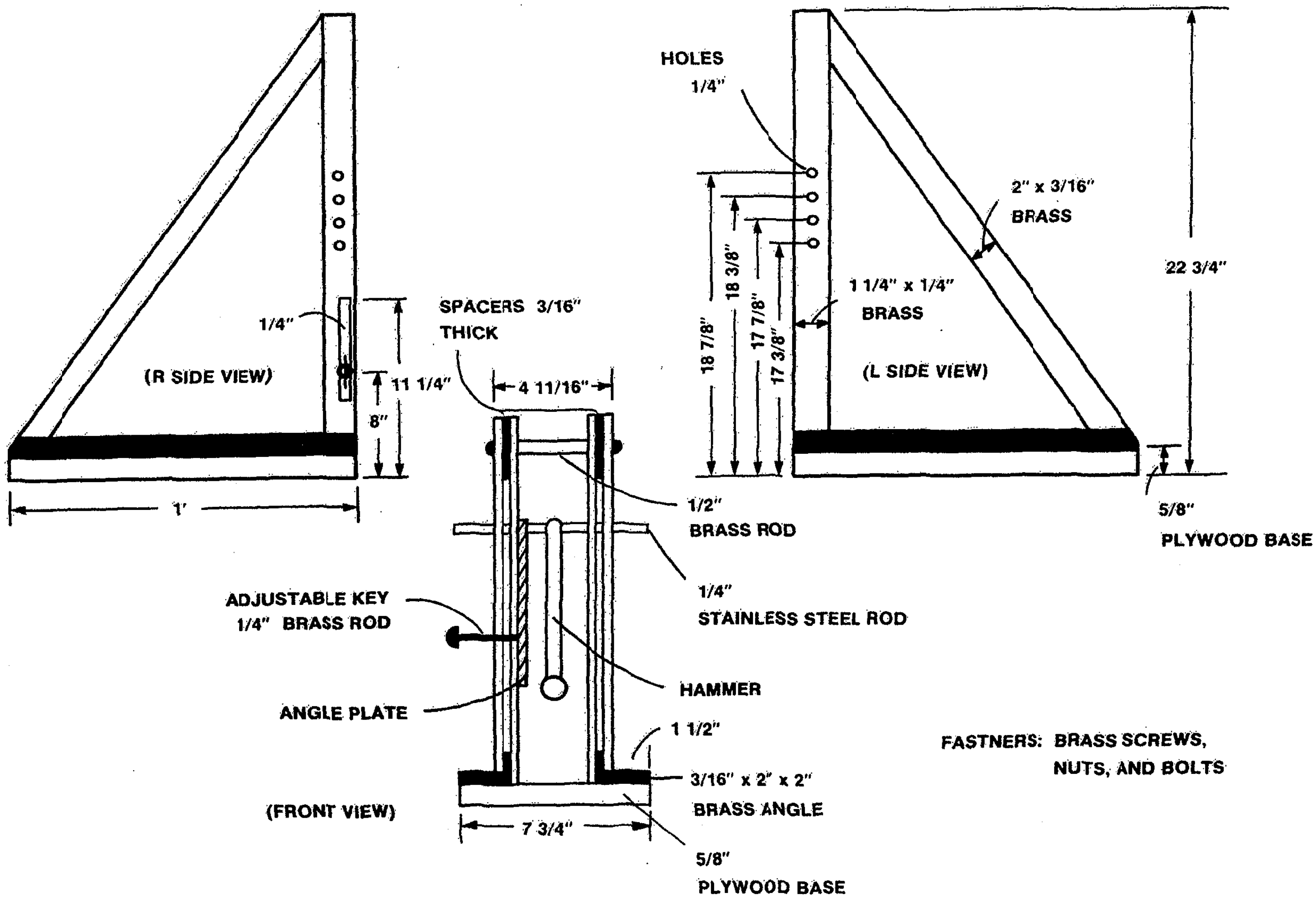
Appendix 2, Figure 3.

KNOCK STAND
(SKETCH NOT TO SCALE)



Appendix 2, Figure 3.

KNOCK STAND
(SKETCH NOT TO SCALE)



UNITS IN INCHES